The CMS data representation using a cascade process of hadronization

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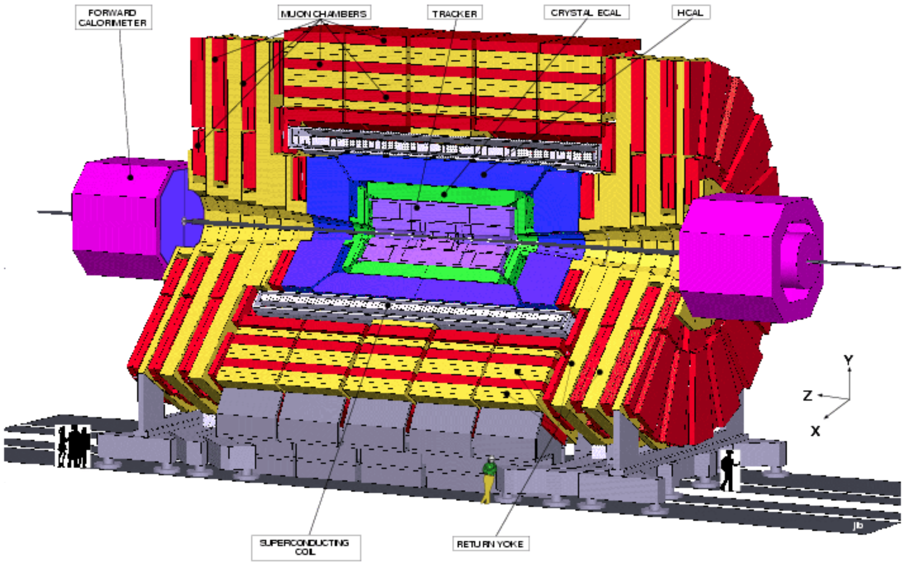
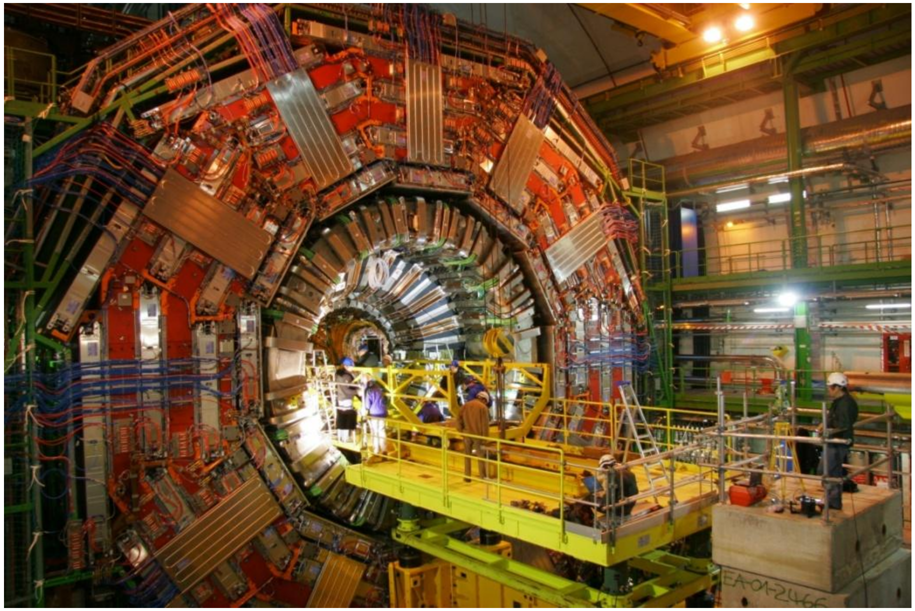
Few pictures

A general view of CMS for those who had not a chance to see it



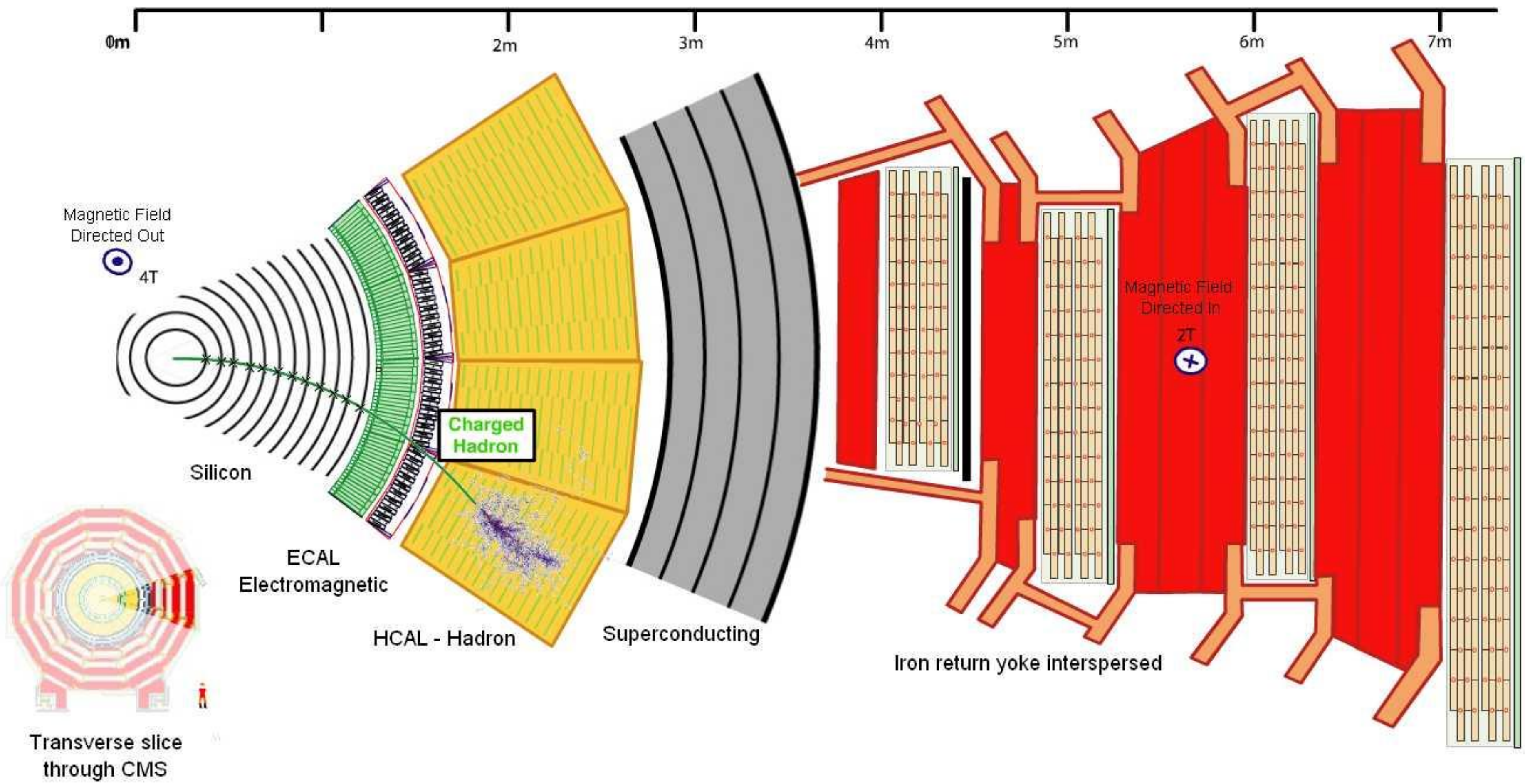
- Total weight: 12 500t
- Overall diameter: 15m
- Overall length: 21.6m
- Magnetic field: 4T
- Electronics channels: 100 000 000

Installation



- General purpose experiment
  - Higgs, QCD, CP, SuSy, extra dimensions…
  - 4π geometry with a multilayer arrangement
    - Tracker
    - Electromagnetic calorimeter
    - Hadronic calorimeter
    - Muon spectrometer
  - Superconducting solenoid
- Effort of thousands of scientists, engineers, technicians from all over the world

Few pictures



Outline

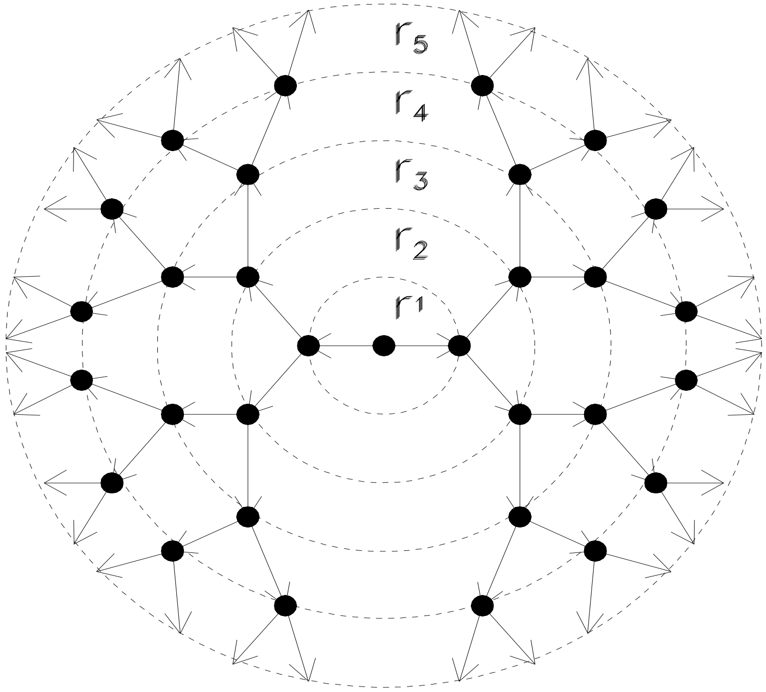
- Description of the cascade model used
- Comparison with the data on mean multiplicities of e^+e^- and pp / $\bar{p}p$ interactions including the CMS data
- The size of the hadronization region

The cascade model

- It is obvious that simultaneous creation of a large number of particles is very improbable
  - Due to the conservation laws, before leaving the range of hadronization, each created particle has to interact somehow with all the others to share properly the available energy, momentum, etc.
  - Because each interaction takes some time, the total time of hadronization will be proportional to the number of produced particles at least in the first order of magnitude

- More economical in time are consecutive ways of hadronization of energy, known as cascade models
  - An example of such models is shown on next transparency

The cascade model



$$\Sigma r_i = r(s),\quad Z = r(s)/\bar{r},\quad n = 2^Z$$

s - square of the total energy

r(*s*) - effective time/radius of the hadronization region

$\bar{r}$ - mean distance between two neighbour steps

$Z = \log_2(\bar{n})$ - some effective number of steps needed to produce $\bar{n}$

$r(s) = ?$

From the Particle Data Group

$$\sigma_{tot}^{ab} = Z^{ab} + B\log^2\left(\frac{s}{s_0}\right) + Y_1^{ab}\left(\frac{s_1}{s_0}\right)^{\eta_1} - Y_2^{ab}\left(\frac{s_1}{s_0}\right)^{\eta_2} \quad (s > s_0)$$

$\sigma_r(s) = B\log^2\left(\frac{s}{s_0}\right)$ - only the term which does not depend on the species of colliding particles. That means – the property of the strong interaction itself.

$B = 0.308mb, \sqrt{s_0} = 5.38GeV$ for all the particles *a* and *b*.

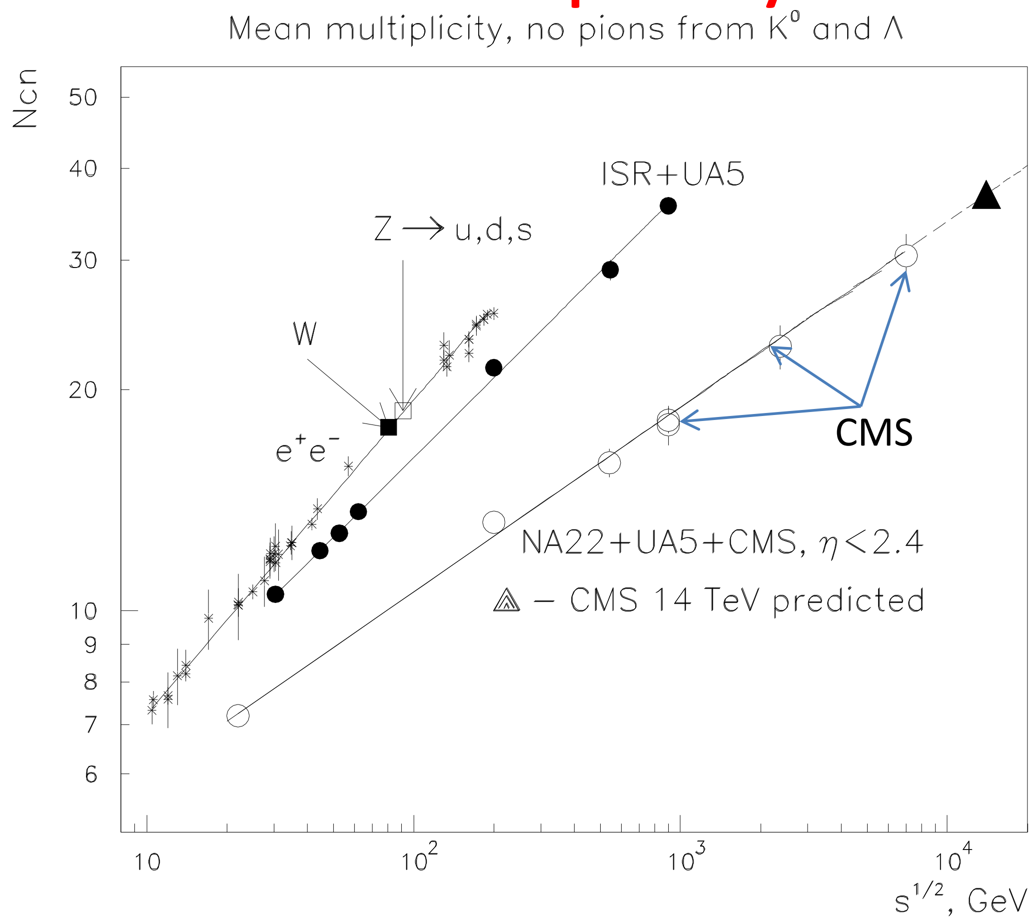
Assumption:

$$r(s) = \frac{1}{m_\pi}\left(1 + \sqrt{\frac{\sigma_r(s)}{\sigma_\pi}}\right)\ GeV^{-1} \qquad \sigma_\pi = (\hbar c)^2 / m_\pi{}^2$$

Now we can fit the experimental data by simple formula:

$$n = 2^{r(s)/\bar{r}}$$ with one free parameter $\bar{r}$

Multiplicity



- The figure shows an excellent linear dependence of log(n) on log(s) for all interactions:
  - e^+e^- annihilation and
  - non-single-diffraction (NSD) events of pp / $\bar{p}p$ (NA22, ISR, UA5, CMS) and
  - decay of heavy mesons into hadrons
- Z=log(n) is the adequate variable for hadronizations!

- The e^+e^- data were fitted by:

$$n = 2^{r(s)/\bar{r}}$$

- The obtained mean distance between two steps:

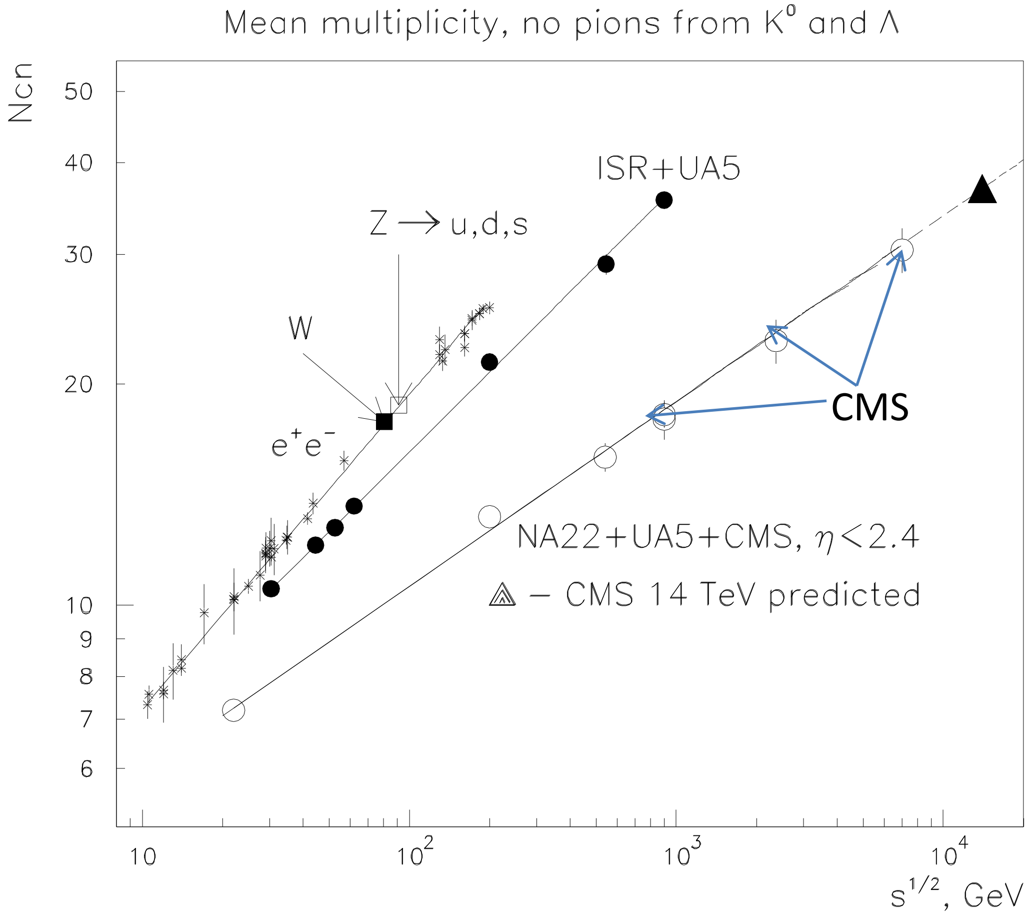
$\bar{r}$=1/0.345, Gev^{-1} or $\bar{r}$=0.57, fermi

  – which appears to be energy independent!

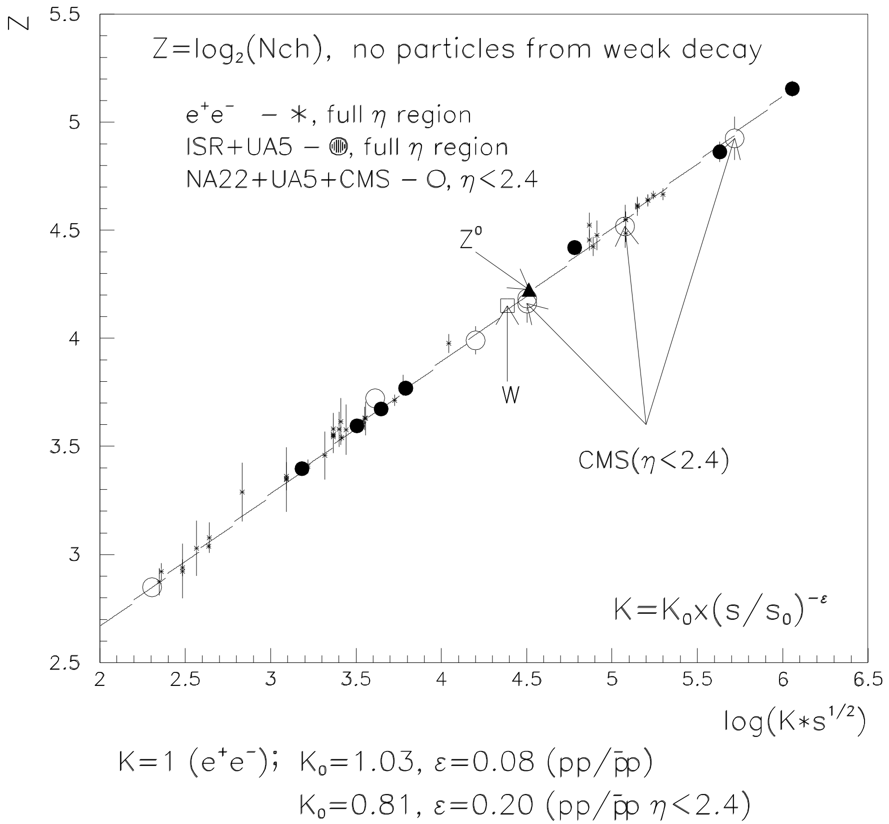
- Multiplicity for hadrons interactions are less from that of e^+e^- at the same energy
  – This is because for hadrons not the total energy is available for hadronization, but only a part of it - *K(s)* x $s^{0.5}$
  – This part can be defined by fitting the hadrons data with $K(s)^2$ x *s* instead of s where

$$K(s) = K_0 \times (\tfrac{s}{s_0})^{-\varepsilon}$$

    - as physicists from cosmic rays do with two free parameters K_0, ε and fixed $\bar{r}$ from e^+e^- data



- The straight lines are the results of the fits
  - with $K(s)$ = 1 for e^+e^-
  - and with the obtained parameters for hadrons:
    - K_0 = 1.03, ε = 0.076 (full range of η) and
    - K_0 = 0.8, ε = 0.20 (η < 2.4)



- This picture shows the mean number of steps as a function of the available energy and all the data are on the same line in this case

The size of the hadronization region

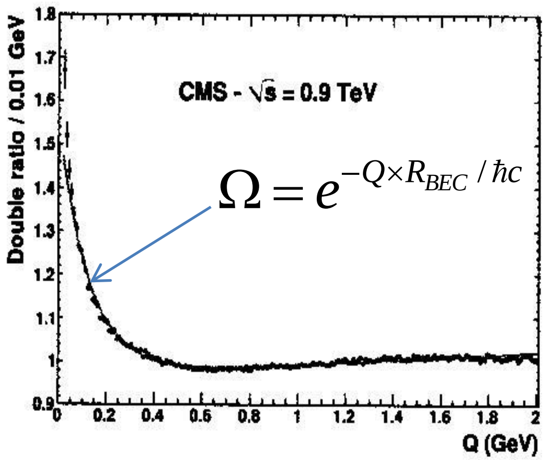
- As it is known the astronomers define the size of stars, simply speaking, by measurement of energy difference in between two photons emitted from the same star by Bose-Einstein correlation (*BEC*)

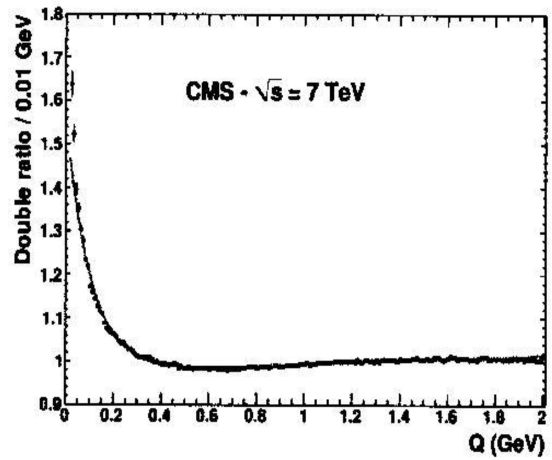
- Kopilov and Podgoretski, using the idea, suggested to measure difference of 4-momentum between two identical bosons with the same sign for definition of the radius of hadronization region (R_{BEC})

$R(Q)$ vs Q (CMS RESULTS)

$$R(Q)=\frac{dN/dQ}{dN_{ref}/dQ} \quad Q=\sqrt{M^2-4m_\pi^2}$$, M - effective mass of 2 identical pions

N_{ref} - the events from a reference sample, expected not to contain BEC





$$Fit: R(Q)=c\times[1+\lambda\Omega]\times(1+\delta\times Q)$$

$$free - c, \lambda, \delta, R_{BEC}$$

Astronomy vs. hadron physics

There are some essential differences between astronomy and hadron physics

1.
   - Astronomy: the sources of photons - atoms, are distributed over the surface of the star
     - The photons from the inside of the star will be absorbed
   - Hadrons: the sources of stable hadrons – resonances are distributed over the full volume of the hadronization region

2.
   - Astronomy: the sources of photons are at the rest in the rest system of the star
   - Hadrons: the sources of stable hadrons have a rather high momentum in the rest system of the hadronization region

3.
   - Astronomy: the size of the star is constant
   - Hadrons: the size of the hadronization region may fluctuate

Few observations

- Having in mind this differences it is rather hard to say definitely what do we measure by *BEC* in the hadron physics

- It is almost impossible to compare numerical values of R_{BEC} from different experiments
  - because of different data selection and different methods of the data analysis used

- But there is a rather well established property:
  - R_{BEC} is almost energy independent but increases with multiplicity

- The present cascade model may give some light on these results

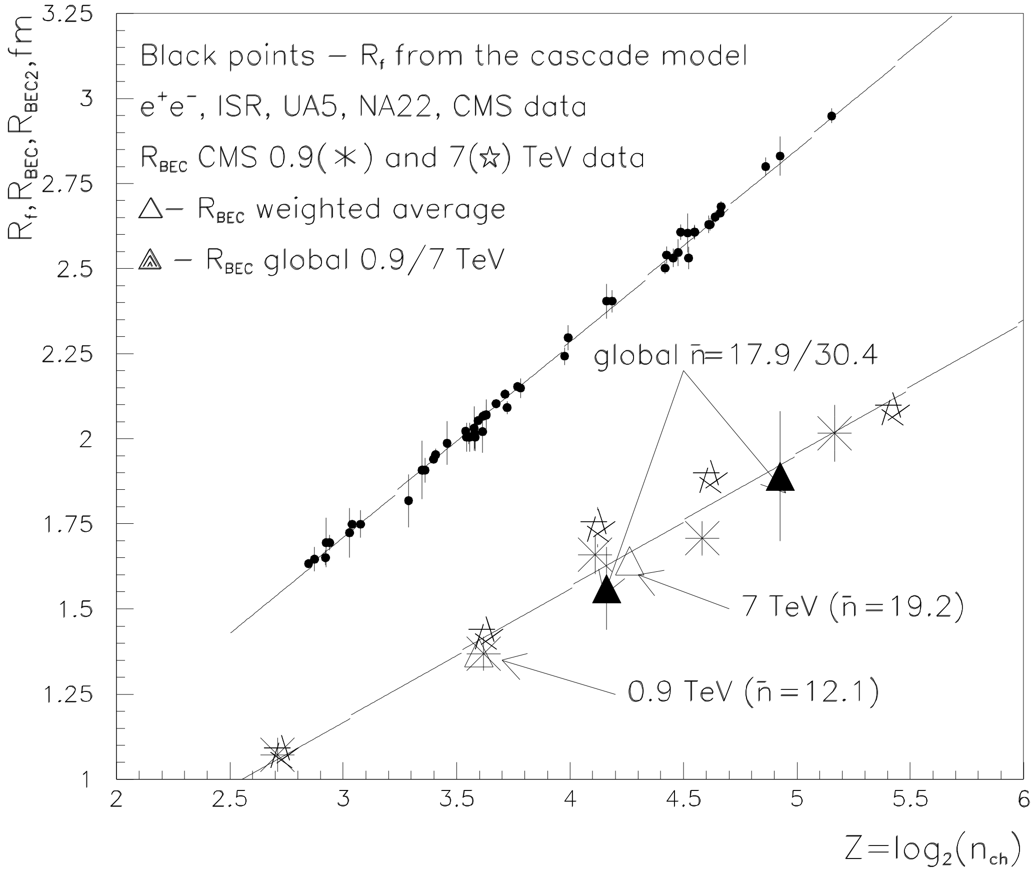
- The main statement of the model is that the hadronization size at fixed number of particles *n* is:

$$r(n) = Z \times \bar{r} = \log_2(n) \times \bar{r}$$

and is energy independent as experimentally $\bar{r}$ appears to be constant

- That means – if one select events with the same *n* but at different energies, *r*(*n*) should be the same

- The rise of *r*(*s*) with the energy is due to the rise of the mean multiplicity
  - This statement is illustrated on the next figures



- The figure shows the size of hadronization obtained by the cascade model in *fermi* $R_f = \hbar c \times r(s)$ as a function of *Z* for all the experimental data used
  - The CMS results of R_{BEC} at energies 0.9 and 7 TeV are presented by stars
    - They are smaller then R_f, but show again a linear dependence on log(n)
  - On figure by triangles are also plotted the weighted average R_{BEC} and global R_{BEC} at 0.9 and 7 TeV for mean charge multiplicities quoted by CMS

- The CMS uses an exponential parameterization for the *BEC* signal

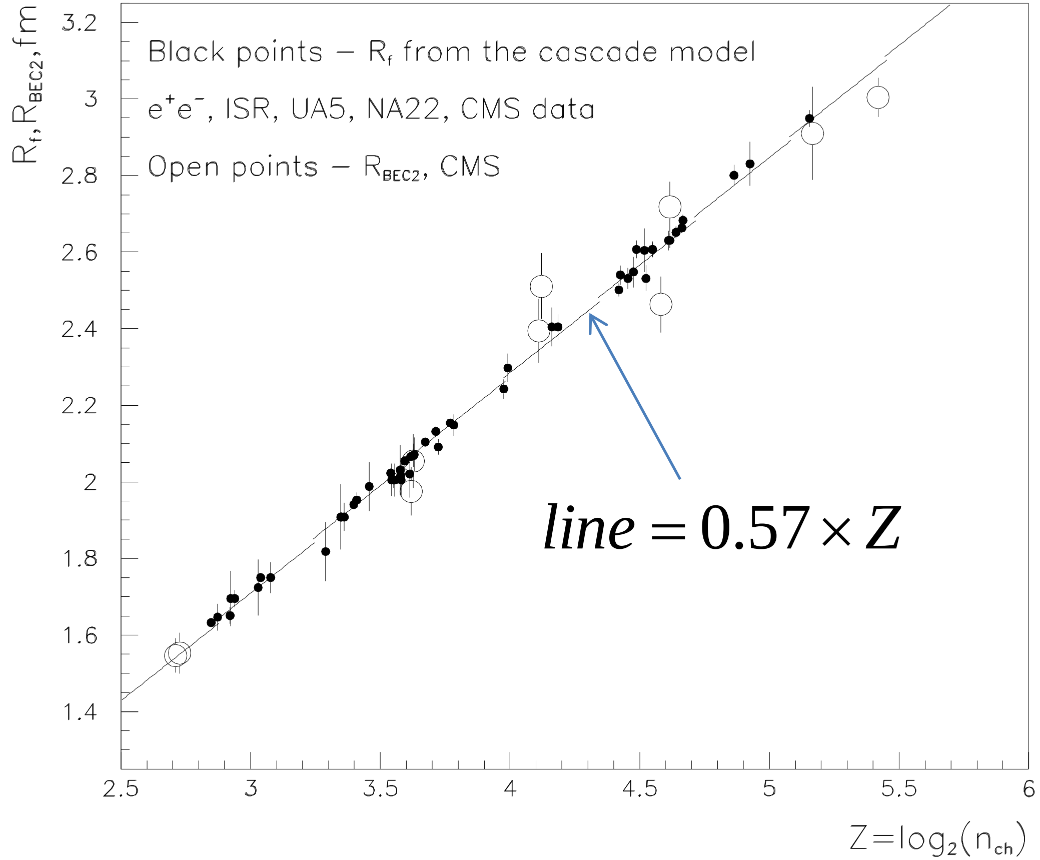
$$\Omega = e^{-Q \times R_{BEC} / \hbar c} \qquad Q = \sqrt{M^2 - 4m_\pi^2}$$

- But there is no common agreement (neither between theoreticians nor experimentalists) about the BEC function
- For the described cascade model the base of power 2 is preferable and if we use:

$$\Omega = 2^{-Q \times R_{BEC2} / \hbar c}$$

then the redefined $R_{BEC2} = R_{BEC} / \log(2)$

- On the next figure R_{BEC2} are plotted by the open circles



- One can see an impressive agreement between the results of the described cascade model and the *BEC* method
  - For R_{BEC2} only statistical errors are shown

- Note that these two methods are absolutely different

Conclusions

1. The CMS data together with the data at lower energies is in a rather good agreement with the described cascade model of multi-particle productions

2. Mean multiplicity is a function of the available energy only and does not depend on the type of reactions including the strong decay of the heavy particles

3. Mean distance between steps of dissipation of the energy into two parts is energy independent (~0.57 *fm*)

4. *Z = log(Nch)* seems to be an adequate variable to study hadronization processes:
   - *Z* is a linear function of *log(s)*
   - radius of hadronization is a linear function of *Z*

5. Radius of the hadronization region defined by the presented cascade model is in agreement with R_{BEC} if base of power *2* is used for the *BEC* signal

6. The decrease of *K* with energy may indicate that strong interactions became more peripheral as energy increases

Suggestion

When studying the energy dependence of various observables in a restricted range of η it may be more useful to use either the energy detected by a hadron calorimeter in the same η range or the effective mass of all charged particles, rather than the total energy of interactions.

I wish to thank Irakli Mandjavidze for useful discussions and help

Thank you for attention

Questions?

First I would like to seize the opportunity and pass a message to concerned people:

ვსარგებლობ შემთხვევით და მივმართავ თანადგომისთვის საქართველოში მეცნიერების განვითარებისთვის პასუხისმგებელ პირებს:

სავარაუდოდ LHC და CMS არანაკლებ ოცი ცლის განმავლობაში იმოქმედებს და საქართველოს მეცნიერთა რამდენიმე თაობა შეძლებს ამ არაჩვეულებრივ დანადგარზე მუშაობას და კვლევების ჩატარებას ფიზიკის მეტად საინტერესო დარგში.

ამისთვის აუცილებელია მიზანდასახული სახსრების გამოყოფა, რათა ჩვენ მოგვეცეს CMS-ში სრულუფლებიანი თანამშრომლობის გაგრძელების შესაძლებლობა.

(an appeal for an adequate financial support of Georgian physicists to continue full-fledged collaboration with CMS)

but, please, if there are any questions I will be happy to answer